



Caloric Value of Some Forest Fuels of the Southern United States

Abstract. — The caloric value of a variety of southern forest fuels was determined in an oxygen bomb calorimeter. High heat values ranged between about 3,600 and 5,200 cal./g. for fuels as sampled and between 4,500 and 5,600 cal./g. for fuels on an ash-free basis. Additional tests of forest fuels from the Southern, Eastern, and North Central United States showed a wider range of heat values: from 3,400 to 7,800 cal./g. for fuels as sampled.

INTRODUCTION

The energy which maintains the chain reaction of combustion is the heat of combustion. This heat value can be measured for any particular fuel by testing samples in an oxygen bomb calorimeter. Because complete combustion occurs in the test apparatus, calorimeter values are an indication of the maximum amount of energy liberated when a material reacts with oxygen. Even though complete combustion never takes place in forest fires, measurements of heat values of fuels are a basic factor in predicting the potential heat release from such fires. These values may also be useful to plant ecologists in calculating energy transfer and efficiency of energy utilization in woodland communities.

METHODS

Samples of various forest and range fuels common to the Southern United States, each consisting of several hundred grams of material, were collected in the field and sent to the Southern Forest Fire Laboratory for testing. All samples were ground in a Wiley Mill to pass a 20-mesh screen, compressed into small pellets, and oven-dried at 85° C. The pellets were then placed in a bomb calorimeter and ignited under 20 atmospheres of pure oxygen.

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Standardized benzoic acid was used to determine the thermal coefficient of the calorimeter system. Corrections were made for the combustion of the ignition wire but not for the energy remaining in the free acids formed by combustion of the fuel. This latter factor has been shown to be small compared with differences in heat values that occur between replicate tests (Gorbatova 1964).

The mineral ash content of each fuel was measured after the samples had been subjected to a temperature of 650° C. in a muffle furnace.

The gross or high heat value in mean calories was computed for each sample tested in the calorimeter. These values were based on the oven-dry weight of fuel which contained inorganic material as sampled in the field. Ash-free heat values were also computed for oven-dry material by correcting for the inorganic residue. Analyses of variance were made, separately and in combination, for the heat values of the vegetative fuels and of the fuels in contact with the ground. Multiple range tests (Duncan 1955) were made when significant differences were found.

After completion of the original study of southern fuels, additional data were collected for other fuels from the Southern, Eastern, and North Central United States. The methods used were the same as above, with heat values being determined on duplicate samples. In addition to total ash

content, silica-free ash values were obtained for some fuels. Statistical analyses of heat values for these additional fuel samples were not made.

RESULTS

The high heat values were computed for the samples of the various southern forest and range fuels tested (table 1). Analyses of variance of combined data showed that the differences between the heat values of the fuels, either as sampled or ash-free, were highly significant. The greatest difference between the heat values of the various fuels as sampled was 1,624 cal./g. After corrections were made for ash content, the difference between the highest and lowest values amounted to 1,063 cal./g.

Ground fuel data from litter layers and organic soil were analyzed. Multiple range tests of ground fuels as sampled showed highly significant differences between the heat values of the lower (decomposed) and the upper (fresh) litter layers. For the hardwood and the pine species, fresh litter had the higher heat value. Pine litter layers were collected in three strata—upper (fresh), middle (weathered), and lower (decomposed). The middle layers had lower heat values than did the fresh layers but higher values than did the decomposed layers. The heat values of the organic soil did not differ significantly from the heat values of the hardwood upper litter.

Multiple range tests indicated that there was no significant difference between the ash-free heat values of the three litter layers collected from stands of slash pine or loblolly pine. Although there was no significant difference between the values of the upper and lower hardwood litter, there was a highly significant difference between the values of the upper and lower litter of scrub oak. The decomposed layer of scrub oak had the higher ash-free heat values. In general, pine needle litter, either ash-free or as sampled, had a higher heat value than did hardwood leaf litter.

Analyses of variance of data on the vegetative fuels (which included material from both dead and live standing plants) were made. The more important differences found included the following: the heat value of slash pine needles was greater than that of loblolly pine needles; the heat values of leaves of scrub oak species were greater than those of leaves of other hardwood species; and the heat values of

needles of pine species were greater than those of leaves of hardwood and grass species. Among the species sampled at several locations (gallberry and Spanish moss), the heat values of the samples differed according to the location. Significant differences were also found between the heat values of live and dead material of the same species (wiregrass and herbaceous plants): living material had higher heat values than did dead material. Similar results have been reported for live and dead standing broomsedge (Golley 1961).

Some rearrangement of average heat values occurred when vegetative fuels were analyzed on an ash-free basis, but the general trends described above remained the same.

On the basis of the gross caloric values determined for the fuels as sampled, the fuels can be grouped in arbitrary classes as follows:

I. < 4,000 cal./g.—Mixed scrub litter (Texas type), dead herbaceous plants, post oak litter, and yaupon litter.

II. 4,000 to 4,500 cal./g.—Live herbaceous plants, lower litter of upland hardwoods, lower litter of scrub oak (from Georgia), dead wiregrass (*Aristida stricta* Michx.), lower litter of loblolly pine, and leaves of upland hardwoods.

III. 4,500 to 5,000 cal./g.—Elm leaves (*Ulmus alata* Michx.), Spanish moss (*Tillandsia usneoides* L.), lower litter of slash pine, upper litter of upland hardwoods, live wiregrass, upper litter of scrub oak (from Georgia), leaves of live oak (*Quercus virginiana* Mill.), organic soil, saw-palmetto fronds (*Serenoa repens* (Bartr.) Small), post oak leaves (*Quercus stellata* Wengen.), turkey oak leaves (*Quercus laevis* Walt.), loblolly pine needles (*Pinus taeda* L.), fetterbush leaves (*Lyonia lucida* (Lam.) K. Koch), and middle litter of loblolly pine.

IV. > 5,000 cal./g.—Middle litter of slash pine, laurel greenbrier leaves (*Smilax laurifolia* L.), redbay leaves (*Persea borbonia* (L.) Spreng.), evergreen yaupon leaves (*Ilex vomitoria* Ait.), upper litter of loblolly pine, gallberry leaves (*Ilex glabra* (L.) Gray), deciduous yaupon leaves (*Ilex decida* Walt.), upper litter of slash pine, and slash pine needles (*Pinus elliotii* Engelm.).

Table 1. — Caloric value of oven-dry forest and range fuels common to the Southern United States

Samples by species-type	Location	Date collected	No. of tests	Caloric value ¹		Coefficient of variation	Ash content	Mean ash-free caloric value ¹
				Cal./g.				
				Mean	Range			
- - Percent - -								
Cal./g.								
Slash pine type								
Palmetto fronds	Georgia	8/31/65	6	4,800	4,772-4,822	0.2	3.4	4,968
Gallberry leaves	Georgia	8/31/65	7	5,213	5,191-5,244	0.2	2.1	5,326
Spanish moss	Georgia	8/31/65	6	4,541	4,525-4,564	0.1	2.9	4,678
Spanish moss	Florida	8/25/65	6	4,627	4,611-4,649	0.1	3.4	4,792
Slash pine needles	Georgia	8/31/65	6	5,206	5,181-5,237	0.2	1.2	5,268
Slash pine upper litter	Georgia	1/5/65	7	5,163	5,128-5,197	0.2	2.1	5,272
Slash pine middle litter	Georgia	1/5/65	6	5,021	4,999-5,060	0.2	2.8	5,167
Slash pine lower litter	Georgia	1/5/65	8	4,622	4,536-4,758	0.6	11.4	5,216
Loblolly pine type								
Loblolly pine needles	Georgia	9/27/65	7	4,945	4,861-5,051	0.6	2.3	5,060
Loblolly upper litter	Georgia	9/27/65	6	5,076	5,063-5,114	0.2	2.7	5,216
Loblolly middle litter	Georgia	9/27/65	6	4,955	4,936-5,047	0.3	3.7	5,187
Loblolly lower litter	Georgia	9/27/65	6	4,432	4,386-4,477	0.4	15.5	5,244
Scrub oak type								
Wiregrass-live	Georgia	9/1/65	6	4,661	4,631-4,693	0.2	2.8	4,798
Wiregrass-dead	Georgia	4/12/65	6	4,393	4,370-4,430	0.3	5.4	4,643
Turkey oak leaves	Georgia	9/1/65	6	4,893	4,833-4,965	0.4	2.8	5,032
Scrub oak upper litter	Georgia	9/1/65	7	4,672	4,609-4,750	0.5	6.0	4,971
Scrub oak lower litter	Georgia	9/1/65	7	4,324	4,035-4,518	1.6	21.9	5,537
Upland hardwood type								
Hardwood leaves	Georgia	9/23/65	7	4,456	4,384-4,543	0.6	7.2	4,800
Hardwood upper litter	Georgia	9/23/65	6	4,634	4,576-4,756	0.7	6.7	4,988
Hardwood lower litter	Georgia	9/23/65	7	4,249	4,016-4,480	1.6	11.9	4,824
Organic soil type								
Greenbrier leaves	N.C.	3/28/66	7	5,027	4,979-5,069	0.3	2.9	5,176
Redbay leaves	N.C.	3/28/66	7	5,048	4,989-5,091	0.3	3.1	5,210
Gallberry leaves	N.C.	3/28/66	6	5,086	5,041-5,120	0.3	1.9	5,183
Fetterbush leaves	N.C.	3/28/66	7	4,970	4,920-5,010	0.2	2.6	5,102
Organic soil	N.C.	11/1/64	6	4,788	4,744-4,875	0.4	14.1	5,575
Texas scrub type								
Herbaceous spp. - live	Texas	5/24/66	6	4,223	4,194-4,245	0.2	9.3	4,656
Herbaceous spp. - dead	Texas	5/24/66	7	3,653	3,533-3,831	1.2	19.0	4,512
Winged elm leaves	Texas	5/24/66	6	4,506	4,465-4,542	0.3	8.5	4,924
Live oak leaves	Texas	5/24/66	6	4,708	4,640-4,771	0.5	4.3	4,919
Scrub litter	Texas	5/24/66	7	3,589	3,501-3,680	0.7	26.5	4,882
Post oak leaves	Texas	5/24/66	6	4,882	4,809-4,920	0.4	2.4	5,000
Post oak litter	Texas	5/24/66	7	3,854	3,668-4,000	1.2	19.9	4,814
Evergreen yaupon leaves	Texas	5/24/66	6	5,061	5,033-5,106	0.2	5.2	5,338
Deciduous yaupon leaves	Texas	5/24/66	6	5,092	5,057-5,132	0.3	4.1	5,311
Yaupon litter	Texas	5/24/66	7	3,982	3,873-4,085	0.7	27.6	5,501

¹ These are high heat values; subtract 300 cal./g. for low heat value.

High heat values of the additional fuels collected after the original study (table 2) showed even greater ranges in values than those reported above. The values for oven-dry material as sampled in the field differed by 2,015 cal./g. for the southern fuels and by 3,767 cal./g. for the eastern and central fuels. If the arbitrary heat-value classes established above are followed, these additional fuels can be grouped thus:

I. Organic soil, inner bark of sweetgum (*Liquidambar styraciflua* L.), and European larch litter (*Larix decidua* Mill.).

II. Reindeer moss (*Cladonia rangiferina* L.), dead bracken fern (*Pteridium latiusculum* (Desv.) Underw.), and hazel leaves (*Corylus cornuta* Marsh.).

III. Hazel twigs, eastern larch needles (*Larix laricina* (Du Roi) K. Koch), European larch needles, white spruce needles (*Picea glauca* (Moench) Voss), jack pine duff (*Pinus banksiana* Lamb.), outer bark of sweetgum, mixed aspen-oak litter, aspen twigs (*Populus tremuloides* Michx.), new needles of sand pine (*Pinus clausa* (Chapm.) Vasey), black spruce needles (*Picea mariana* (Mill.) B. S. P.).

IV. Needles and twigs of balsam fir (*Abies balsamea* (L.) Mill.), twigs of white and black spruce, aspen leaves, needles and twigs and litter of jack pine, sand pine twigs, sand pine needles, and bark of white birch (*Betula papyrifera* Marsh.).

DISCUSSION

The data given in this report are high heat values because the water vapor produced by combustion is condensed to liquid in the calorimeter. In a forest fire, moisture resulting from combustion is not condensed and therefore retains its heat of vaporization. In such a case, the quantity of heat produced is expressed as a low heat value.

The proportion of carbon, hydrogen, and oxygen in a specific fuel influences the quantity of water vapor released when it burns. Among the fuels tested, exact proportions of these elements were not known. At present, the best estimate of heat stored in the water of reaction is that used for wood (Byram 1959)—about 300 cal./g. When approximations of low heat values are desirable, as in estimating the heat yield from combustion of forest fuels in a

Table 2.—Caloric value of oven-dry forest fuels from the Eastern United States

Samples by species-type	Location	Date collected	Caloric value ¹	Total ash content	SiO ₂ -free ash content	Ash-free caloric value ¹
			Cal./g.	- - Percent - -		Cal./g.
Sweetgum outer bark	Macon, Ga.	1/20/69	4,709	6.4	—	5,010
Sweetgum inner bark	Macon, Ga.	1/20/69	3,810	7.4	—	4,092
Organic soil	Lakeland, Fla.	11/7/68	3,428	40.00	—	4,799
Sand pine new needles	Ocala, Fla.	3/18/69	5,379	2.0	1.2	5,487
Sand pine new needles	Ocala, Fla.	5/14/69	4,865	—	—	—
Sand pine old needles	Ocala, Fla.	3/18/69	5,443	2.1	1.9	5,557
Sand pine old needles	Ocala, Fla.	5/14/69	5,242	—	—	—
Sand pine twigs	Ocala, Fla.	3/18/69	5,293	1.5	0.8	5,372
Sand pine twigs	Ocala, Fla.	5/14/69	5,112	—	—	—
Eastern larch needles	Mexico, Pa.	10/11/67	4,637	7.39	4.34	4,980
European larch needles	State College, Pa.	10/11/67	4,608	8.47	—	4,998
European larch litter	State College, Pa.	10/11/67	3,996	20.33	—	4,808
Dead bracken fern	Mille Lacs, Minn.	5/5/69	4,414	7.79	2.61	4,758
Mixed aspen-oak litter	Mille Lacs, Minn.	5/5/69	4,758	7.71	5.20	5,119
Aspen leaves	Ely, Minn.	6/26/69	5,053	4.60	4.55	5,285
Aspen twigs	Ely, Minn.	6/26/69	4,864	3.16	3.12	5,018
Hazel leaves	Ely, Minn.	6/25/69	4,424	4.98	4.75	4,644
Hazel twigs	Ely, Minn.	6/25/69	4,556	3.74	3.60	4,726
Jack pine needles	Ely, Minn.	6/25/69	5,102	1.94	1.41	5,201
Jack pine twigs	Ely, Minn.	6/25/69	5,176	1.66	1.44	5,262
Jack pine litter	Ely, Minn.	6/26/69	5,148	2.62	1.41	5,283
Jack pine duff	Ely, Minn.	6/26/69	4,700	9.80	1.74	5,161
Balsam fir needles	Ely, Minn.	6/25/69	5,060	2.90	2.66	5,207
Balsam fir twigs	Ely, Minn.	6/25/69	5,040	2.73	2.56	5,178
White spruce needles	Ely, Minn.	6/26/69	4,700	4.91	3.34	4,931
White spruce twigs	Ely, Minn.	6/26/69	5,070	3.50	2.32	5,247
Black spruce needles	Ely, Minn.	6/25/69	4,926	2.38	1.98	5,043
Black spruce twigs	Ely, Minn.	6/25/69	5,125	3.08	1.84	5,283
White birch bark	Ely, Minn.	6/25/69	7,765	1.30	0.68	7,864
Reindeer moss	Ely, Minn.	6/25/69	4,360	1.86	0.72	4,441

¹ These are high heat values; subtract 300 cal./g. for low heat value.

natural atmosphere, 300 cal./g. should be deducted from the appropriate high heat values.

The chemical composition of a fuel influences its caloric value as well as the amount of water produced in combustion. For example, the heat values of several plant constituents vary as follows: 9,300 cal./g. for fats, 6,300 cal./g. for lignin, 5,700 cal./g. for proteins, 5,100 cal./g. for carbohydrates, and 3,700 cal./g. for glucose (Kramer and Kozlowski 1960). This variation explains, in a general way, why resinous conifers and waxy evergreen shrub species have higher caloric values than do most hardwood or grass species.

Two exceptions to the generalization that conifers have higher caloric values than do hardwoods have been noted among the fuels from Minnesota. Bark from white birch had the highest caloric value of any forest fuel tested at this laboratory (7,763 cal./g.). This value would indicate a very high content of fat or essential oil. Such oils are, in fact, extracted on a commercial scale from birch bark (Kramer and Kozlowski 1960). Quaking aspen showed the highest heat value among the hardwood leaves tested. This value was as high as those of some pine species and probably indicates a relatively high fat content.

Part of the variation in caloric value between fuels may be the result of collecting samples at different times of the year. Richards (1940) has noted that a number of species in the Northern Rocky Mountains exhibit seasonal variation in heat value. He found that the heat value of one species increased 600 cal./g. during the fire season. Short et al. (1966) noted that some browse species in Colorado exhibit seasonal changes in heat value of about 400 cal./g. Such seasonal variation may account for the difference found between the heat value of gallberry leaves collected in Georgia dur-

ing August and in North Carolina during March. The effect of season was obvious for sand pine samples collected from the same trees in March and May (table 2).

Caloric values for fresh litter and decomposed litter under a pine plantation have been reported by Ovington and Heitkamp (1960); in almost all cases, the fresh litter contained more energy than did the decomposed litter. This same relationship between fresh and decomposed litter was evident in the present study.

Differences in caloric value between litter fuels resulted, in part, from the dilution of the combustible material with inorganic ash. When corrections were made for ash, however, the lower layers were as high in heat value as were the upper layers, or higher. Similar results have been reported by Bockock (1964) for several hardwood species. This higher heat value which results when the decomposed litter is corrected for ash content indicates that the low-energy components (carbohydrates and cellulose) decomposed more rapidly than did the high-energy components (lignin). Dilution of lower litter layers with inorganic matter cannot be ignored, however, because fuels are not ash-free in the field.

The wide range in heat values reported here (from 3,428 to 7,763 cal./g.) is not unexpected. The caloric values of different vegetative and litter materials in England were found to vary from 3,317 to 5,187 cal./g. (Ovington and Heitkamp 1960), and in Russia a similar variation from 3,770 to 5,250 cal./g. was noted (Gorbatova 1964). However, the full influence of a difference of 100 cal./g. or even 4,000 cal./g. on the behavior of a forest fire is unknown. For this reason, the statistical differences reported here may not be significant to fire behavior. Only through further study of the effect of heat value on fire behavior can this point be resolved.

LITERATURE CITED

- Bocock, K. L.
 1964. Changes in the amounts of dry matter, nitrogen, carbon, and energy in decomposing woodland leaf litter in relation to the activities of the soil fauna. *J. Ecol.* 52 (2): 273-284.
- Byram, G. M.
 1959. Combustion of forest fuels, Chapter 3, pp. 61-89. *In* Kenneth P. Davis, *Forest fire: control and use*. New York: McGraw-Hill Book Co., Inc.
- Duncan, D. B.
 1955. Multiple range and multiple F tests. *Biometrics* 11: 1-9.
- Golley, Frank B.
 1961. Energy values of ecological materials. *Ecology* 42: 581-584.
- Gorbatova, N. G.
 1964. Calorific value of certain varieties of forest fuels, pp. 35-38. *In* N. P. Kurbatskii [Ed.], *Soviet progress in forest fire control*. New York: Consultants Bureau Enterprise, Inc.
- Kramer, P. J., and Kozlowski, T. T.
 1960. *Physiology of trees*. 642 pp., illus. New York: McGraw-Hill Book Co., Inc.
- Ovington, J. D., and Heitkamp, D.
 1960. The accumulation of energy in forest plantations in Britain. *J. Ecol.* 48: 639-646.
- Richards, L. W.
 1940. Effect of certain chemical attributes of vegetation on forest inflammability. *J. Agr. Res.* 60: 833-838.
- Short, H. L., Dietz, D. R., and Remmenga, E. E.
 1966. Selected nutrients in mule deer browse plants. *Ecology* 47: 222-229.

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